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In re Patent Application of:)
Shunpei YAMAZAKI et al.)
Application No.: 10/684,410) Examiner: C. Melissa Koslow
Filed: October 15, 2003) Group Art Unit: 1755
For: LIGHT-EMITTING ORGANIC COMPOUND AND)
EL DISPLAY DEVICE UTILIZING THE SAME)

VERIFICATION OF TRANSLATION

Commissioner for Patents
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Sir:

I, Izumi Matsukuma, C/O Semiconductor Energy Laboratory Co., Ltd. 398, Hase, Atsugi-shi, Kanagawa-ken 243-0036 Japan, herewith declare:

that I am well acquainted with both the Japanese and English Languages; and

that to the best of my knowledge and belief the followings is a true and correct translation of the US Patent Application No. H11-336119 filed on November 26, 1999.

I further declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

Date: this 24th day of March, 2005

A handwritten signature in black ink, appearing to read "Izumi Matsukuma".

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[Number of Prepayment Note] 002543

[Payment Amount] 21000

[List of Attachment]

[Attachment] Specification 1

[Attachment] Drawing 1

[Attachment] Abstract 1

5

[Proof] required

[Document Name] Specification

[Title of the Invention] ORGANIC ELECTROLUMINESCENCE DISPLAY DEVICE
AND METHOD FOR MANUFACTURING THE SAME

[Scope of Claims]

5 [Claim 1]

An organic electro luminescence display device in which a high-molecular type organic electro luminescence layer is provided in a pixel portion, characterized in that ionic impurities contained in the above-mentioned organic electro luminescence layer are set to be equal to 0.1 ppm or lower and a volume resistivity in the range of $3 \times 10^{10} \Omega \text{ cm}$ or larger.

10 [Claim 2]

An organic electro luminescence display device in which pixels containing a TFT formed on the substrate and a high-molecular type organic electro luminescence layer electrically connected to the TFT are arranged, characterized in that:

the above-mentioned organic electro luminescence layer are provided between the
15 anodes and the cathodes;

ionic impurities contained in the organic electro luminescence layer are set to be equal to 0.1 ppm or lower; and

a volume resistivity in the range of $3 \times 10^{10} \Omega \text{ cm}$ or larger.

[Claim 3]

20 An organic electro luminescence display device in which pixels containing anodes arranged in stripes, cathodes arranged in stripes to be orthogonal to the anode and a high-molecular type organic electro luminescence layer provided between the anodes and the cathodes, characterized in that:

ionic impurities contained in the organic electro luminescence layer are set to be
25 equal to 0.1 ppm or lower; and

a volume resistivity in the range of $3 \times 10^{10} \Omega \text{ cm}$ or larger.

[Claim 4]

An organic electro luminescence display device according to any one of claims 1 to

3, characterized in that ionic impurities include sodium element or potassium element.

[Claim 5]

An electronic apparatus characterized by utilizing an organic electro luminescence display device described in any one of claims 1 to 4 as its display portion.

5 [Claim 6]

A method for manufacturing an organic electro luminescence display device in which a high-molecular type organic electro luminescence layer, characterized by comprising a step of purifying the above-mentioned organic electro luminescence layer so that ionic impurities contained in the above-mentioned organic electro luminescence layer are set to be 10 equal to 0.1 ppm or lower and a volume resistivity in the range of $3 \times 10^{10} \Omega \text{ cm}$ or larger.

[Claim 7]

A method for manufacturing an organic electro luminescence display device according to claim 6, characterized by utilizing a dialysis method as the above-mentioned purification process.

15 [Claim 8]

A method for manufacturing an organic electro luminescence display device according to claim 6, characterized by utilizing a electrodialysis method as the above-mentioned purification process.

[Claim 9]

20 A method for manufacturing an organic electro luminescence display device according to claim 7 or 8, characterized by repeating the above-mentioned purification process several times.

[Claim 10]

A method for manufacturing an organic electro luminescence display device, 25 characterized by comprising a step of forming an anode layer or a cathode layer over the organic electro luminescence layer without allowing the organic electro luminescence layer to be exposed to the atmosphere after a step of forming a high-molecular type organic electro luminescence layer.

[Detailed Description of the Invention]

[0001]

[Technical Field to which the Invention pertains]

The present invention relates to an organic EL display device using a high-molecular
5 organic EL material (including a complex that contains a metal in its molecular formula) capable of providing Electro Luminescence (EL). The present invention also relates to an electronic apparatus including the above-mentioned organic EL display device as its display portion. It should be noted that the above-mentioned EL display device will be also referred to as the OLED (Organic Light-emitting Diode).

10 [0002]

[Prior Art]

Development of a display device including an organic EL layer as a self-light emitting element that utilizes EL phenomenon (the organic EL display device) has been proceeded in these years. Since the organic EL display device is of the self-light emitting type, no back
15 light is required unlike a liquid crystal display device or the like. Moreover, the organic EL display device exhibits a wide viewing angle. So, the organic EL display device is advantageous to be used as a display portion for a portable device which is likely to be used outdoors.

[0003]

20 A light-emitting layer as a principal portion of the organic EL device is made of an insulating material. When a voltage is applied across a cathode and an anode with the light-emitting layer interposed therebetween, carriers (electrons and holes) are injected into the light-emitting layer and recombined to emit light. Thus, a current flowing through the light-emitting layer is caused by the recombination of carriers. An organic EL material that
25 can be used for the organic EL display device is described in, for example, Japanese Patent Application Laid-Open No. Hei 2-311591.

[0004]

In a light-emitting element such as a light-emitting diode in which a semiconductor

junction is formed, Na (sodium) that may exhibit an adverse effect as a movable ion causes a resistance value of the light-emitting layer to decrease, and therefore, can cause a current flow other than that caused by the carrier recombination. When such an unnecessary current flows, an amount of heat generation is increased and the light-emitting layer is more likely to deteriorate. The same disadvantage may occur in the organic EL device. However, any sufficient countermeasure against the disadvantage caused by the movable ion has not been provided for the organic EL material under the present conditions.

[0005]

[Problems to be solved by the Invention]

The present invention is intended to provide an organic EL display device with high reliability. The present invention is also intended to provide an electronic apparatus with a highly reliable display portion by utilizing such an organic EL display device as its display portion.

[0006]

[Means for Solving the Problems]

In accordance with the present invention, in order to prevent a current from flowing due to reasons other than the carrier recombination, a volume resistivity of an organic EL layer is set to be in the range from 1×10^{11} to $1 \times 10^{12} \Omega \text{ cm}$ (preferably, in the range from 1×10^{12} to $1 \times 10^{13} \Omega \text{ cm}$). In addition, in order to obtain the volume resistivity, ionic impurities contained in the organic EL layer are set to be equal to 0.1 ppm or lower (preferably, equal to 0.01 ppm or lower). Ionic impurities typically refer to sodium (Na), potassium (K), and the like. Specifically the sodium concentration can be calculated to be 7×10^{17} atoms/cm³ or lower (preferably, 7×10^{16} atoms/cm³ or lower). However, it is appropriate to consider that the total concentration of Na and K should meet the concentration of ionic impurities.

[0007]

When the organic EL layer is formed of a low-molecular type organic EL material for obtaining the above-mentioned organic EL layer, the organic EL layer can be purified by a zone purification method, a sublimation purification method, a recrystallization method, a

distillation method, a filtration method, a column chromatography method, or a reprecipitation method. On the other hand, in case of a high-molecular type organic EL material, values of molecular weight are likely to vary over a certain range since degree of polymerization cannot be completely controlled. Thus, a melting point cannot be decided unambiguously at a certain value, and therefore, it becomes difficult to perform purification.

5 In this case, it is appropriate to perform a dialysis method or a high-performance liquid chromatography method. It is appropriate to perform an electrodialysis method for efficiently eliminating ionic impurities in the dialysis method. However, a purification process is required to be repeated several times in order to reduce the concentration of the

10 ionic impurities to the above-mentioned range. More specifically, it is desirable to repeat a purification process at least three times or more, and more preferably, five times or more. Instead of repeating the same purification process, it is of course possible to perform two or more different processes.

[0008]

15 As set forth above, the present invention is characterized in that a high-molecular type organic EL material containing ionic impurities at the concentration of 0.1 ppm or lower (preferably, at the concentration of 0.01 ppm or lower) and having a volume resistivity in the range of 1×10^{11} to $1 \times 10^{12} \Omega \text{ cm}$ (preferably, in the range from 1×10^{12} to $1 \times 10^{13} \Omega \text{ cm}$) is formed, and an organic EL display device is fabricated by using it.

20 [0009]

In addition, the high-molecular type organic EL material to be used in the present invention can be used a material having a molecular weight in the range of 8×10^2 to 2×10^6 g/mol (typically, in the range of 1×10^4 to 1×10^5 g/mol).

[0010]

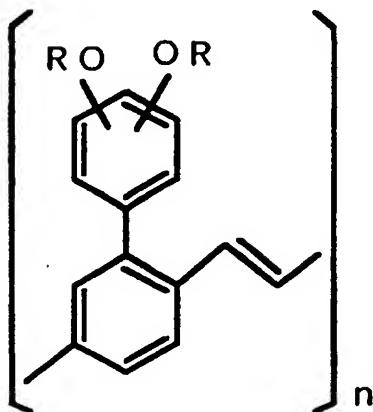
25 The typical high-molecular type organic EL materials that can be used in the present invention include PPV (polyphenylenevinylene), which includes various types. For example, the molecular formulas 1 and 2 in the separate sheet have been presented (in the article by H. Shenk, H. Becker, O. Gelsen, E. Kluge, W. Kreuder, and H. Spreitzer entitled "Polymers for

"Light-emitting Diodes" in Euro Display Proceedings 1999, pp.33-37).

[0011]

[Formula 1]

5



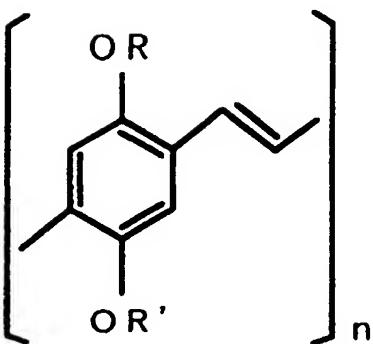
10

[0012]

15

[Formula 2]

20



25

[0013]

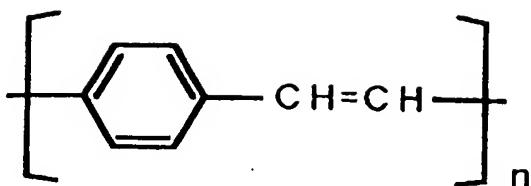
Alternatively, polyphenylvinyl having a molecular formula as described in Japanese Patent Application Laid-Open No. Hei 10-92576, as shown in the separate sheet, can also be

used.

[0014]

[Formula 3]

5

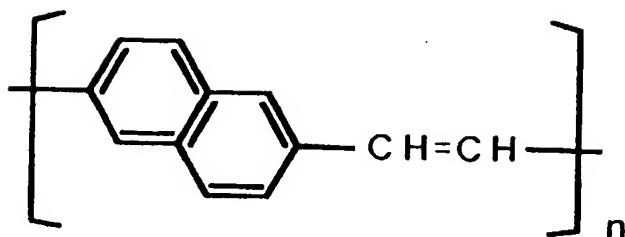


10

[0015]

15

[Formula 4]



20

25

[0016]

Various methods can be employed for forming an EL layer of the above-mentioned high-molecular type organic EL materials. In particular, a spin coating method is preferred

in view of simplicity in its process. More specifically, in the spin coating method, a solute which is a major component of a thin film is dissolved in a solvent and the obtained solution is applied to an underlying member by means of a spinner or the like. Thereafter, the solvent is volatilized in a baking process to form a thin film.

5 [0017]

In accordance with the present invention, a solvent containing a high-molecular type organic EL material is applied by means of a spinner, and a heat treatment is then performed at a temperature that is sufficiently low for preventing crystallization of the high-molecular type organic EL material (specifically, at a glass-transition temperature or lower) so as to 10 volatilize the solvent. As a result, a thin film made of the high-molecular type organic EL material can be formed on the substrate. That is to say, means for applying solution containing a high-molecular type organic EL material and thereafter baking it are needed for forming a high-molecular type organic EL layer.

[0018]

15 Furthermore, since a high-molecular type organic EL material as well as a low-molecular type organic EL material is vulnerable to oxygen, a conductive film to be formed following formation of the high-molecular type organic EL layer is desirably formed in such a condition that the high-molecular type organic EL layer is not exposed to surrounding atmosphere containing water and/or oxygen. Accordingly, it can be preferable 20 to have means for forming the above-mentioned high-molecular type organic EL layer (means for conducting a spin coating method in the present invention) and means for forming the conductive film to function as a cathode or an anode on the layer (means for conducting a vapor deposition method, a sputtering method, or the like) in the same thin-film formation apparatus.

25 [0019]

For meeting the above-mentioned requirement, a thin-film formation apparatus of the multi-chamber type is suitable. The present invention relates to a technique to form an organic EL display device having high reliability by utilizing such a thin-film formation

apparatus.

[0020]

With the above-mentioned structure, a current that is caused by reasons other than the carrier recombination can be prevented from flowing through a high-molecular type organic 5 EL layer in an organic EL display device, and deterioration caused by unnecessary heat generation can be prevented. Accordingly, it is possible to obtain an organic EL display device with high reliability. Moreover, an electronic apparatus with a highly reliable display portion can be obtained by utilizing such an organic EL display device as its display portion.

[0021]

10 [Embodiments of the Invention]

One embodiment of the present invention will be described with reference to Fig. 1. In Fig. 1, reference numeral 101 denotes a substrate having an insulating surface. As the substrate 101, an insulating substrate such as a quartz substrate can be used. Alternatively, various kinds of substrate, such as a glass substrate, a ceramic substrate, a crystallized glass 15 substrate, a metal substrate, or a plastic substrate, can be used by providing an insulating film on a surface thereof.

[0022]

On the substrate 101, pixels 102 are formed. Although only three of the pixels are illustrated in Fig. 1, a higher number of pixels are actually arranged in matrix. For example, 20 pixels are arranged in a matrix of 640×480 for a VGA class, and in a matrix of 1024×768 for an XGA class. In each of the pixels 102, two TFTs are formed; one of them is a switching TFT 103, and the other is a current-control TFT 104. A drain of the switching TFT 103 is electrically connected to a gate of the current-control TFT 104. Furthermore, a drain of the current-control TFT 104 is electrically connected to a pixel electrode 105 (which 25 in this case, also functions as a cathode of an organic EL device). The pixel 102 is thus formed.

[0023]

Respective wirings of the TFT as well as the pixel electrode can be formed of a metal

film having a low resistivity. An aluminum alloy film may be used for this purpose. In addition, the TFT can have any structure including a known structure.

[0024]

Following the fabrication of the pixel electrode 105, a cathode layer 106 that contains

5 a metal having a low work function is formed over all of the pixel electrodes. It should be noted that the outline of the cathode layer 106 is indicated by a dotted line in Fig. 1. This is because the cathode layer 106 has a thickness which is as thin as several nm, and it cannot be clearly known whether the cathode layer 106 is formed as a layer or in an island-shape.

[0025]

10 As a material for the above-mentioned cathode layer 106 that contains a metal having a low work function, lithium fluoride (LiF), lithium oxide (Li₂O), barium fluoride (BaF₂), barium oxide (BaO), calcium fluoride (CaF₂), calcium oxide (CaO), strontium oxide (SrO), or cesium oxide (Cs₂O) can be used. Since these are insulating materials, short-circuiting between the pixel electrodes does not occur even when the cathode layer 106 is formed as a

15 layer.

[0026]

It is of course possible to use a known conductive material such as a MgAg electrode as the above-mentioned compound 106. However, in this case, the cathode in itself has to be selectively formed or patterned into a certain shape in order to avoid short-circuiting between

20 the pixel electrodes.

[0027]

Over the cathode layer 106 that contains a metal having a low work function, an organic EL layer 107 (an electroluminescence layer) is formed. Although any known material and/or structure can be employed for the organic EL layer 107, a material capable of emitting white light is used in the present invention. With respect to the structure of the organic EL layer, only a light-emitting layer for providing sites for the carrier recombination may be included in the organic EL layer. Alternatively, if necessary, an electron injection layer, an electron transport layer, a hole transport layer, an electron blocking layer, a hole

25

element layer, or a hole injection layer may be further layered to form the organic EL layer. In the present specification, all of those layers intended to realize injection, transport or recombination of carriers are collectively referred to as the organic EL layer.

[0028]

As an organic EL material to be used as the organic EL layer 107, a high-molecular type organic EL material of a polymer type can be used. The structure illustrated in Fig. 1 is of the color display type in which an organic EL layer for emitting white light is combined with a color filter. Alternatively, a color display scheme in which an organic EL layer for emitting blue or blue-green light is combined with fluorescent material (fluorescent color conversion layer; CCM), or another color display scheme in which organic EL layers respectively corresponding to RGB are overlaid each other to provide a color display, can also be employed.

[0029]

One of the features of the present invention is that a high-molecular type organic EL material purified to an extremely high degree of purity is used as an organic EL layer. For a high-molecular type organic EL material, a dialysis method or a high-performance liquid chromatography method can be used. In particular, an electrodialysis method is preferred for eliminating ionic impurities.

[0030]

In the dialysis method, a polymerized high-molecular type organic EL material is put in a semi-permeable membrane made of a cellulose or the like, and immersed in a solvent, e.g., pure water. The semi-permeable membrane is usually fixed by being supported between fine metal mesh partitions, or by being attached to a porous supporting member such as a circle plate made of half-melt glass. In the electrodialysis method, a voltage is applied between metal mesh partitions supporting the semi-permeable membrane, thereby resulting in a higher moving speed for ionic impurities which can realize efficient purification.

[0031]

In accordance with the present invention, the above-mentioned purification process is

repeated so that the concentration of ionic impurities contained in the high-molecular type organic EL material which forms the organic EL layer reaches a level of 0.1 ppm or lower (preferably, a level of 0.01 ppm or lower). Ionic impurities typically refer to Na, K, and the like. The above-mentioned concentration range of the ionic impurities provides the organic
5 EL layer with a volume resistivity in the range of 1×10^{11} to $1 \times 10^{12} \Omega \text{ cm}$ (preferably, in the range from 1×10^{12} to $1 \times 10^{13} \Omega \text{ cm}$). Thus, a current caused by reasons other than the carrier recombination is prevented from flowing.

[0032]

In the case where the organic EL layer includes only a light-emitting layer, i.e., only
10 a single layer of a high-molecular organic EL material, the light-emitting layer is required to meet conditions in which the concentration of the contained sodium is equal to or lower than 0.1 ppm (preferably, at 0.01 ppm or lower) and the volume resistivity is in the range from 1×10^{11} to $1 \times 10^{12} \Omega \text{ cm}$ (preferably, in the range from 1×10^{12} to $1 \times 10^{13} \Omega \text{ cm}$).

[0033]

15 It is of course critical to prevent sodium from being mixed into the high-molecular organic EL material from the surrounding atmosphere during a process step for purifying the high-molecular organic EL material which forms the organic EL layer and a process step for forming a film thereof.

[0034]

20 Over the thus formed organic EL layer 107, a transparent conductive film is formed as an anode 108. As the transparent conductive film, a compound of indium oxide and tin oxide (referred to as ITO), a compound of indium oxide and zinc oxide, tin oxide (SnO_2), or zinc oxide (ZnO) can be used.

[0035]

25 Over the anode 108, an insulating film as a passivation film 109 is provided. As the passivation film 109, a silicon nitride film or a silicon nitride oxide film (represented as SiOxNy) is preferably used.

[0036]

one for obtaining blue light. These color filters are formed at positions respectively corresponding to the different pixels 102, and thus, different color of light can be obtained for the respective pixels. In theory, this is the same as the color display scheme in a liquid crystal display device which uses color filters. It should be noted that the position corresponding to the pixel refers to the position aligned with the pixel when viewed from the direction which is normal to the opposing substrate. More specifically, the color filters 113a to 113c are provided so as to overlap the pixels respectively corresponding thereto when viewed from the direction normal to the opposing substrate.

[0040]

It should be noted that the color filter is a filter for improving the color purity of light which has passed therethrough by extracting light of a specific wavelength. Accordingly, in the case where the light component of the wavelength to be extracted are not many, there may be disadvantages in which the light of that wavelength has an extremely small luminance or a deteriorated color purity. Thus, although no limitation is imposed to an organic EL layer for emitting white light which can be used in the present invention, it is preferable that the spectrum of the emitted white light includes emission spectrums of red, green and blue light components having purity of as high as possible.

[0041]

The color filters 113a to 113c, similarly to the light-shielding films 112, can contain a drying agent such as barium oxide. In this case, a resin film containing a drying agent and a pigment of red, green or blue color may be used as a color filter.

[0042]

It should be noted that although not illustrated herein, the opposing substrate 110 is adhered to the active matrix substrate by means of a sealing agent, so that a space designated with reference numeral 114 is a closed space. The closed space 114 may be filled with inert gas (noble gas or nitrogen gas), or with inert liquid. Alternatively, the closed space 114 may be filled with a transparent adhesive so as to adhere the whole surface of the substrate. Moreover, it is preferable to dispose a drying agent such as barium oxide in the closed space

114. Since the organic EL layer 107 is very vulnerable to water, it is desirable to prevent water from entering the closed space 114 as much as possible. Furthermore, it is advantageous to fill the closed space 114 with inert liquid containing crown ether or cryptand. Crown ether has an ability to trap sodium by being combined with them, and thus a gettering
5 effect can be expected to be realized.

[0043]

As the opposing substrate 110, it is necessary to use a transparent substrate so as not to prevent light from traveling. For example, a glass substrate, a quartz substrate, or a plastic substrate is preferably used. In addition, as the light-shielding film 112, a thin film capable
10 of satisfactorily shielding light, e.g., a titanium film, a resin film including a black-colored pigment or carbon, can be used. It is advantageous to use as the light-shielding film 112, a resin containing a drying agent.

[0044]

In the organic EL display device having the above-mentioned construction in
15 accordance with the present invention, the organic EL layer contains ionic impurities at the concentration of 0.1 ppm or lower (preferably, at the concentration of 0.01 ppm or lower) and a volume resistivity in the range of 1×10^{11} to $1 \times 10^{12} \Omega \text{ cm}$ (preferably, in the range from 1×10^{12} to $1 \times 10^{13} \Omega \text{ cm}$). Accordingly, a current caused by reasons other than the carrier
recombination can be prevented from flowing through an organic EL layer that is contained in
20 an organic EL device, and deterioration caused by unnecessary heat generation can be prevented.

[0045]

Thus, it is possible to obtain an organic EL display device with high reliability. Moreover, an electronic apparatus with a highly reliable display portion can be obtained by
25 utilizing such an organic EL display device as its display portion. In the organic EL display device in accordance with the present invention, light emitted from the organic EL device passes through the opposing substrate to be emitted toward observer's eyes. Accordingly, the observer can recognize an image through the opposing substrate. In this situation, one of

the features of the organic EL display device in accordance with the present invention is that the light-shielding film 112 is disposed between the organic EL device and the observer so as to conceal the gap 111 between the pixel electrodes 105. Thus, the contour between the pixels can be made clear, thereby resulting in an image display with high definition.

5 Furthermore, the light-shielding films 112 and the color filters 113a to 113c are disposed on the opposing substrate 110, and the opposing substrate 110 also functions as a ceiling material for suppressing deterioration of the organic EL device. When the light-shielding films 112 and the color filters 113a to 113c are disposed on the active matrix substrate, additional film-formation and patterning steps are required, thereby resulting in a reduced manufacturing

10 yield. By providing the light-shielding films 112 and the color filters 113a to 113c on the opposing substrate, reduction in the manufacturing yield can be suppressed. Furthermore, the structure in accordance with the present invention, in which the opposing substrate 110 is provided with the light-shielding films 112 and the color filters 113a to 113c and adhered to the active matrix substrate by means of the sealing agent, has features common to the

15 structure of a liquid crystal display device. Accordingly, it is possible to fabricate the organic EL display device of the present invention with most of an existing manufacturing line for liquid crystal display devices. Thus, an amount of equipment investment can be significantly reduced, thereby resulting in a reduction in the total manufacturing cost.

[0046]

20 [Embodiment 1]

A first embodiment of the invention is described here. A description will be made here on a method for fabricating TFTs of a pixel portion and driving circuit portions provided around the same simultaneously. For simplicity of the description, only a CMOS circuit is shown which is a basic circuit for such driving circuits.

25 [0047]

First, as shown in Fig. 2A, an base film 301 having a thickness of 300 nm is formed on a glass substrate 300. In the present embodiment, a silicon oxinitride film is laminated as the base film 302. At this time, the density of nitrogen in the region in contact with the glass

substrate 300 is preferably in the range from 10 to 25 wt%.

[0048]

Next, an amorphous silicon film (not shown) having a thickness of 50 nm is formed on the base film 301 using a known film forming method. The film is not limited to an amorphous silicon film, and it may be any semiconductor film (and any microcrystalline semiconductor film) including an amorphous structure. The film may alternatively be a compound semiconductor film including an amorphous structure such as an amorphous silicon germanium film. The thickness may be in the range from 20 to 100 nm.

[0049]

The amorphous silicon film is then crystallized using known techniques to form a crystalline silicon film (also referred to polycrystalline silicon film or polysilicon film) 302. Known methods for crystallization include thermal crystallization utilizing an electrically heated furnace, laser anneal crystallization utilizing laser light and lamp anneal crystallization utilizing infrared light. In the present embodiment, crystallization is performed using excimer laser light utilizing XeCl gas. While pulse-oscillated excimer laser light formed in a linear configuration is used in the present embodiment, a rectangular configuration may alternatively be used. Continuously oscillated argon laser light or continuously oscillated excimer laser light may be used.

[0050]

When Nd-YAG laser (wavelength 1.06 μm) is used, second harmonic or third harmonic is used and the illumination with a beam is carried out to crystallize the above mentioned semiconductor film with 100 to 500 J/cm^2 energy density. The beam is formed in a linear or rectangular configuration by the optical light system.

[0051]

In this embodiment, although the crystalline silicon film is used as the active layer of the TFT, it is also possible to use an amorphous silicon film. Note that it is possible to form the active layer of the switching TFT, in which there is a necessity to reduce the off current, by the amorphous silicon film, and to form the active layer of the current control TFT by the

crystalline silicon film. Electric current flows with difficulty in the amorphous silicon film because the carrier mobility is low, and the off current does not easily flow. In other words, the most can be made of the advantages of both the amorphous silicon film, through which current does not flow easily, and the crystalline silicon film, through which current easily

5 flows.

[0052]

Then, as shown in Fig. 2B, a protective film 303 constituted by a silicon oxide film is formed to a thickness of 130 nm on the crystalline silicon film 302. A thickness within the range from 100 to 200 nm (preferably from 130 to 170 nm) may be chosen. Other types of 10 insulation films may be used as long as silicon is included therein. The protective film 303 is provided to prevent direct exposure of the crystalline silicon film to plasma during doping with an impurity and to enable delicate density control.

[0053]

Resist masks 304a through 304b are formed on the protective film to allow doping 15 with an impurity element that provides n-type conductivity (hereinafter referred to as n-type impurity element) through the protective film 303. As the n-type impurity element, an element belonging to the group XV, typically, phosphorous or arsenic may be used. In the present embodiment, phosphorous is added in a density of 1×10^{18} atoms/cm³ using a plasma doping process in which phosphine (PH₃) is plasma-excited without performing mass 20 separation on the same. It is obviously possible to use an ion implantation process which involves mass separation. The dose is adjusted such that n-type impurity regions 305 and 306 formed at this step include the n-type impurity element in a density in the range from 2×10^{16} to 5×10^{19} atoms/cm³ (typically, from 5×10^{17} to 5×10^{18} atoms/cm³).

[0054]

25 Next, as shown in Fig. 2C, the protective film 303 is removed to activate the added element belonging to the group XV. While any known technique may be used as means for activation, activation is carried out by means of illumination with excimer laser light. Obviously, the invention is not limited to excimer laser light, and pulse-oscillated or

continuously oscillated laser light may be used. Since the purpose is to activate the added impurity element, illumination is preferably carried out with an energy at which the crystalline silicon film is not melted. The illumination with laser light may be carried out with the protective film 303 unremoved.

5 [0055]

When the impurity element is activated with laser light, activation may be simultaneously performed using furnace annealing. Referring to activation using furnace annealing, a thermal process at a temperature in the range from 450 to 550°C.

[0056]

10 As a result of this step, the edges of the n-type impurity regions 305 and 306, i.e., the boundaries (bonding portions) between the n-type impurity regions 305 and 306 and the regions around the same which are not doped with the n-type impurity element becomes clear. Therefore, very preferable bonding portions can be formed between the LDD regions and the channel forming region when the TFT is completed later.

15 [0057]

Next, as shown in Fig. 2D, unnecessary portions of the crystalline silicon film are removed to form island-shaped semiconductor films (hereinafter referred to as active layers) 307 through 310. Next, as shown in Fig. 2E, a gate insulation film 311 is formed to cover the active layers 307 through 310. An insulation film including silicon with a thickness in 20 the range from 10 to 200 nm (preferably in the range from 50 to 150 nm) may be used as the gate insulation film 311. This film may have either of single-layer or multi-layer structures. In the present embodiment, a 110 nm thick silicon nitride oxide film is used.

[0058]

Next, a conductive film having a thickness of 200 to 400 nm is formed, and 25 patterning is carried out to form gate electrodes 312 to 316. The end portions of the gate electrodes 312 to 316 can also be made taper-shaped. Note that in this embodiment, the gate electrode and an extended wiring line (hereinafter referred to as a gate wiring line) electrically connected to the gate electrode are formed of different materials. Specifically, a material

having a resistance lower than the gate electrode is used for the gate wiring line. This is because a material which can be finely worked is used for the gate electrode and a material which has a low wiring resistance though fine working can not be made is used for the gate wiring line. Of course, the gate electrode and the gate wiring line may be formed of the same material.

5 [0059]

While the gate electrode may be constituted by single-layer conductive films, multi-layer films such as double-layer or triple-layer structures are preferably used as needed.

Any known conductive film may be used as the material for the gate electrodes. However, 10 as described above, it is preferable to use a material which can be finely worked, specifically, can be patterned into a line width of 2 μm or less. Specifically, it is possible to use thin films including tantalum (Ta), titanium (Ti), molybdenum (Mo), tungsten (W), chromium (Cr) or conductive silicon (Si) or thin films which are nitrides of the same (typically tantalum nitride 15 films, tungsten nitride films or titanium nitride films) or alloy films which are combinations of the above elements (typically Mo-W alloys or Mo-Ta alloys) or silicide films including the above elements (typically tungsten silicide films or titanium silicide films). Such films may be used in either of single-layer and multi-layer structures.

[0060]

In the present embodiment, multi-layer films formed by a 50 nm thick tantalum 20 nitride (WN) film and 350 nm thick tungsten (W) film are used. They may be formed using a sputtering process. An inert gas such as Xe, Ne or the like may be used as the sputtering gas to prevent the films from coming off due to stress.

[0061]

At this time, the gate electrodes 313 and 316 are formed such that they overlap a part 25 of the n-type impurity regions 305 and 306 respectively with the gate insulation film 311 interposed. Such overlaps become LDD regions which overlap the gate electrodes later.

[0062]

Next, as shown in Fig. 3A, an n-type impurity element (which is phosphorous in the

present embodiment) is added in a self-aligning manner using the gate electrodes 312 through 316 as masks. An adjustment is performed such that resultant impurity regions 317 through 323 are doped with phosphorous in a density in the range from 1/2 to 1/10 (typically from 1/3 to 1/4) of that in the n-type impurity regions 305 and 306. Specifically, a density in the 5 range from 1×10^{16} to 5×10^{18} atoms/cm³ (typically from 3×10^{17} to 3×10^{18} atoms/cm³) is preferable.

[0063]

Next, as shown in Fig. 3B, resist masks 324a through 324d are formed to cover the gate electrodes and the like, and an n-type impurity element (which is phosphorous in the 10 present embodiment) is added to form impurity regions 325 through 331 heavily doped with phosphorous. An ion doping process utilizing phosphine (PH₃) is performed again, and the density of phosphorous in those regions is adjusted such that it is within the range from 1×10^{20} to 1×10^{21} atoms/cm³ (typically from 2×10^{20} to 5×10^{21} atoms/cm³).

[0064]

15 While this step forms the source regions or drain regions of the n-channel type TFTs, a part of the n-type impurity regions 320 through 322 formed at the step shown in Fig. 3A is left for the switching TFT.

[0065]

Next, as shown in Fig. 3C, the resist masks 324a through 324d are removed to form 20 a new resist mask 332. A p-type impurity element (which is boron in the present embodiment) is added to form impurity regions 333 and 334 heavily doped with boron. An ion doping process utilizing diborane (B₂H₆) is performed here to add boron in a density within the range from 3×10^{20} to 3×10^{21} atoms/cm³ (typically from 5×10^{20} to 1×10^{21} atoms/cm³).

25 [0066]

While the impurity regions 333 and 334 have already been doped with phosphorous in a density within the range from 1×10^{20} to 1×10^{21} atoms/cm³, boron is added here in a density which is at least three times the same density. As a result, the previously formed

n-type impurity regions are completely inverted into the p-type to serve as p-type impurity regions.

[0067]

The n-type or p-type impurity element added in the respective density is activated after removing the resist mask 332. The means for annealing may be furnace annealing, laser annealing or lamp annealing. In the present embodiment, a thermal process at 550°C is performed for four hours in a nitrogen atmosphere in an electrically heated furnace.

[0068]

At this time, it is critical to eliminate oxygen from the surrounding atmosphere to a level of as low as possible. This is because when oxygen of even only a small amount exists, an exposed surface of the gate electrode is oxidized, which results in an increased resistance and later makes it difficult to form an ohmic contact with the gate electrode. Accordingly, the oxygen concentration in the surrounding atmosphere for the above-mentioned activation process is set at 1 ppm or lower, preferably at 0.1 ppm or lower.

[0069]

After the activation process is completed, the gate wiring 335 having a thickness of 300 nm is formed. As a material for the gate wiring 335, a metal film containing aluminum (Al) or copper (Cu) as its main component (occupied 50 to 100% in the composition) can be used. The gate wiring 335 is arranged as the gate wiring 211 shown in Fig. 3 so as to provide electrical connection for the gate electrodes 314 and 315 of the switching TFT (see Fig. 3D).

[0070]

The above-described structure can allow the wiring resistance of the gate wiring to be significantly reduced, and therefore, an image display region (pixel portion) with a large area can be formed. More specifically, the pixel structure in accordance with the present embodiment is advantageous for realizing an organic EL display device having a display screen with a diagonal size of 10 inches or larger (or 30 inches or larger).

[0071]

Thereafter, a first interlayer insulating film 336 is formed, as shown in Fig. 4A. As the first insulating film 336, a single-layered insulating film containing silicon, or a layered film obtained through combination thereof, can be used. A thickness of the first insulating film 336 can be set in the range from 400 nm to 1.5 μ m. In the present embodiment, the first 5 interlayer insulating film 336 is formed to have a layered structure in which a silicon oxide film having thickness of 800 nm is formed on a silicon nitride oxide film having a thickness of 200 nm.

[0072]

Furthermore, a heat treatment is performed in the atmosphere containing hydrogen 10 of 3 to 100% at a temperature of 300 to 450°C for 1 to 12 hours so as to realize a hydrogenation treatment. In this treatment, dangling bonds in the semiconductor film are terminated with thermally excited hydrogen. As other processes for hydrogenation, a plasma hydrogenation process can be performed in which hydrogen generated by plasma are used. It should be noted that the hydrogenation process may be performed during the formation of 15 the first interlayer insulating film 336. More specifically, the above-mentioned hydrogenation process can be performed after forming a silicon nitride oxide film having a thickness of 200 nm, followed by the formation of the remaining 800 nm portion of the silicon oxide film.

[0073]

Then, contact holes are formed through the first interlayer insulating film 336, and 20 source wirings 337 to 340 and drain wirings 341 to 343 are then formed. In the present embodiment, the electrode is formed as a layered film with a three-layered structure, including a 100 nm thick Ti film, a 300 nm thick Al film containing Ti, and a 150 nm thick Ti film, that are continuously formed by a sputtering method. Other conductive films can be of 25 course used.

[0074]

Thereafter, a first passivation film 344 having a thickness in the range of 50 to 500 nm (typically, in the range of 200 to 300 nm) is formed. In the present embodiment, a

silicon nitride oxide film having a thickness of 300 nm is used as the first passivation film 344.

Alternatively, a silicon nitride film may be instead used.

[0075]

It is advantageous to perform a plasma treatment with a gas containing hydrogen such as H₂, NH₃, prior to the formation of the silicon nitride oxide film. Hydrogen excited in the pre-process is supplied to the first interlayer insulating film 336. By performing the heat treatment in such a situation, the film properties of the first passivation film 344 are improved.

Simultaneously, the hydrogen added to the first interlayer insulating film 336 is diffused downwards, thereby resulting in efficient hydrogenation of the active layer.

10 [0076]

Then, a second interlayer insulating film 345 made of an organic resin is formed, as shown in Fig. 4B. As the organic resin, polyimide, polyamide, acrylic, BCB (benzocyclobutene) or the like can be used. The second interlayer insulating film 345 is provided mainly for planarization, and thus, acrylic capable of exhibiting satisfactory planarizing properties is preferred. In the present embodiment, an acrylic film is formed so as to have a thickness sufficient for realizing the planarization of steps formed by the TFTs. Preferably, the acrylic film has a thickness in the range of 1 to 5 μm (more preferably, in the range of 2 to 4 μm).

[0077]

20 Thereafter, a contact hole is formed in the second interlayer insulating film 345 and the first passivation film 344 to reach the drain wiring 343, and then the pixel electrode 346 is formed. In the present embodiment, an aluminum alloy film (an aluminum film containing titanium of 1 wt%) having a thickness of 300 nm is formed as the pixel electrode 346. Reference numeral 347 denotes an end portion of the adjacent pixel electrode.

25 [0078]

Fig. 10 illustrates a thin-film formation apparatus to be used for continuously forming the organic EL layer and the anode layer. More specifically, Fig. 10 illustrates an apparatus to be used for continuously forming a transparent conductive film as the anode layer,

a high-molecular type organic EL layer as the light-emitting layer, a metal film containing an element belonging to Group I or II in the periodic table as the cathode layer, and a silicon nitride film or a silicon nitride oxide film as the second passivation layer.

[0079]

5 In Fig. 10, reference numeral 401 denotes a transportation chamber in which transportation of a substrate into and out of the apparatus is performed. The transportation chamber is also referred to as a load/unload chamber. A carrier 402 to which the substrate is mounted is placed in the transportation chamber 401. Two of the transportation chambers 401 may be provided; one of them is used for transporting the substrate into the apparatus, 10 while the other is for transporting the substrate out of the apparatus. Reference numeral 403 denotes a common chamber provided with a mechanism 405 for transporting the substrate 404 (hereinafter referred to as the transportation mechanism). The transportation mechanism 405 includes a robot arm or the like for handling a substrate.

[0080]

15 A plurality of process chambers (designated as 407 to 411, respectively) are coupled to the common chamber 403 via gates 406a to 406f. In the configuration shown in Fig. 10, the pressure in the common chamber 403 is reduced to several mTorr to several tens of mTorr, and the respective process chambers are decoupled from the common chamber 403 by means of the gates 406a to 406f. In this case, the process chamber 408 for solution 20 application process is filled with inert gas so that the process is to be performed under a normal pressure. Accordingly, a process chamber 401 for vacuum evacuation is provided between the common chamber 403 and the process chamber 408 for solution application process.

[0081]

25 Accordingly, when the respective chambers are provided with an evacuation pump, respective processes can be performed in vacuum. As an evacuation pump, an oil rotation pump, a mechanical booster pump, a turbo molecular pump, or a cryopump can be used, and in particular, the cryopump is preferred since it is effective for eliminating water.

[0082]

Further by referring to Fig. 10, reference numeral 407 denotes a process chamber for forming the cathode layer (hereinafter referred to as the third film-formation process chamber). In this chamber 407, an auxiliary electrode for assisting the cathode is formed.

5 A vapor deposition method or a sputtering method is usually used, and among them, the vapor deposition method is more preferred since it introduces less damage to a substrate to be processed. In either case, the third film-formation process chamber 407 is decoupled from the common chamber 403 by the gate 406b so that the film formation process can be performed in vacuum. On the other hand, in the case where the vapor deposition method is

10 performed as a vapor-phase film-formation method, a vapor source has to be provided. A metal film to be often used as the cathode layer is made of an element belonging to Group I or II in the periodic table. However, this kind of metal film is likely to be oxidized, and therefore, it is desirable to protect a surface thereof. In addition, the required film thickness therefor is small. Thus, a conductive film having a low resistivity is auxiliarily provided to

15 reduce a resistance value of the cathode as well as to protect the cathode. As the conductive film having a low resistivity, a metal film containing aluminum, copper or silver as its main component can be used. In the present embodiment, lithium fluoride is used for a cathode layer 348 shown in Fig. 4C, and the cathode layer 348 is formed by a vacuum vapor deposition method to have a thickness of 5 nm.

20 [0083]

By further referring to Fig. 10, reference numeral 408 denotes a process chamber for applying a solution containing the high-molecular type organic EL material by a spin coating method (hereinafter referred to as the solution application process chamber). As set forth above, since the organic EL material is very vulnerable against water, the solution application

25 process chamber 408 is required to be always held in inert atmosphere.

[0084]

For transportation of a substrate, the pressure in the vacuum evacuation process chamber 412 is reduced to the same level as the common chamber 403. Thereafter, the gate

406d is opened under that condition, and a substrate is transported. The gate 406d is then closed, and the vacuum evacuation process chamber 412 is purged by inert gas to a normal pressure. Then, the gate 413 is opened at the time when the pressure returns to the normal level, and the substrate is transported to the solution application process chamber 408. This
5 transportation may be performed for every stage. Alternatively, the transportation may be performed by means of specially-dedicated transportation means.

[0085]

The solution application process chamber 408 is provided with a fixed head for holding and rotating the substrate, and means for supplying a solvent containing an organic
10 EL material onto the substrate by an appropriate amount. The fixed head can be of the vacuum chuck type which has a simple configuration. However, the substrate may be deformed in a pattern corresponding to a shape of a suction port, resulting in a deviation in a thickness of the resultant organic EL layer. While the organic EL layer is to be formed to have a thickness in the range of 100 to 200 nm, the deviation of the film thickness thereof is
15 likely to lead to deteriorated display quality in which, e.g., the intensity of light emission is varied.

[0086]

Figs. 11A through 11F respectively illustrate various configurations of the fixed head to be used for reducing such a deviation in the film thickness to the minimum level. The
20 suction port has a shape in which concentric grooves or a plurality of openings are provided. Evacuation to vacuum is performed through a coupling port provided beneath the suction port so that a suction force is scattered two-dimensionally. The fixed head with such a configuration is integrated with upper and lower plates.

[0087]

25 More specifically, Fig. 11A illustrates a top view of an upper plate 1101 of the fixed head, and a plurality of openings 1103 are formed in concentric patterns. Fig. 11B illustrates a lower plate 1102 provided with an evacuation port 1105 combined with a cross-shaped common groove 1104. Fig. 11C illustrates a cross-sectional view taken along line A-A' in

Figs. 11A and 11B in which the upper plate 1101 is overlaid the lower plate 1102. Fig. 11D illustrates another example in which a plurality of openings 1108 are provided in an upper plate 1106 of the fixed head. Fig. 11E illustrates a lower plate 1107 provided with an evacuation port 1110 combined with a circular-shaped common groove 1109. Fig. 11F 5 illustrates a cross-sectional view taken along line B-B' in Figs. 11D and 11E in which the upper plate 1106 is overlaid the lower plate 1107.

[0088]

In the organic EL layer, PVK (polyvinylcarbazole), Bu-PBD (2-(4'-tert-butylphenyl)-5-(4"-biphenyl)-1,3,4-oxydiazole), coumarin6, DCM1 10 (4-dicyanomethylene-2-methyl-6-p-dimethylaminostyryl-4H-pyran), TPB (tetraphenyl butadiene), or Nile Red is dissolved into 1,2-dichloromethane or chloroform, and the resultant solution is applied by a spin coating method. The number of revolutions is set in the range from about 500 to 1000 rpm, and the spinning continues for 20 to 60 seconds to obtain an uniformly applied film.

15 [0089]

It should be noted that prior to the film formation of the above-mentioned organic EL material, the purification process (typically, the dialysis method) is repeated at least three times or more, preferably five times or more, so that the concentration of the sodium contained therein is reduced to 0.1 ppm or lower (preferably 0.01 ppm or lower). Thus, the 20 concentration of the sodium contained in the organic EL layer 349 shown in Fig. 4C is reduced to 0.1 ppm or lower (preferably to 0.01 ppm or lower) and a volume resistivity of the organic EL layer 349 is set in the range of 1×10^{11} to $1 \times 10^{12} \Omega \text{ cm}$ (preferably, in the range from 1×10^{12} to $1 \times 10^{13} \Omega \text{ cm}$).

[0090]

25 After completion of the solution application process, the gate 413 is opened and the substrate 412 is transported to the vacuum evacuation process chamber 412. After the gates 413 and 406d are closed, vacuum evacuation is performed in such a condition. When the pressure in the vacuum evacuation process chamber 412 reaches the same reduced pressure